Operational Present Status and Reliability Analysis of the Upgraded EAST Cryogenic System


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Content

- Introduction
- Upgrade of EAST Cryogenic System
- Experimental Operation Present Status
- Reliability Analysis
- Conclusion and Perspective
EAST Tokamak & Cryogenic System

Warm Compressor Station & 10000 Nm3 helium gas tanks

EAST Cryogenic System (ECS)

Cool-down

One of Critical Sub-systems

EAST Superconducting Tokamak

Cold Components

• PF Coils, TF Coils, TF Coil Cases, Thermal Shields
• Buslines, HTS Current Leads (CL), Built-in Cryopumps

Total cold mass

• 250 tons
Two refrigeration cycles with LN2 pre-cooling

- Claude cycle with 3 turbines to produce refrigeration power at 4.5K for SC
- Reverse-Brayton cycle with two turbine in series to produce refrigeration power at 80K for THS
- Equivalent refrigeration power: 2 kW/4.5 K
Two new MYCOM oil injected screw compressors

- Installed in parallel with 7 old compressors, which can used as spare on standby
- Every set has two stages, creating a low, medium and high pressure
- **Mass flow rate:** (LP) 135 g/s, (HP) 185 g/s, regulated by the slide valves
- **Pressure:** (LP) 0.1043 MPaA, (MP) 0.3~0.42 MPaA, (HP) 2.1 MPaA, controlled by 9 control valves
**Turbine System Upgrade**

- **Five new dynamic gas bearing turbines with eddy current brake**
  - To replace original oil-gas hybrid bearing turbines
  - T3 replaced with full dynamic gas bearing helium turbine TD
  - T4 replaced with two big break power gas bearing turbines TA1 & TA2 in series

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<table>
<thead>
<tr>
<th>Turbine Expanders</th>
<th>TB</th>
<th>TC</th>
<th>TD</th>
<th>TA</th>
<th>TA</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TA1</td>
<td>TA2</td>
</tr>
<tr>
<td><strong>Type</strong></td>
<td>HET 10</td>
<td>HET10</td>
<td>HEXT 1.9</td>
<td>HET 10</td>
<td>HET10</td>
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<tr>
<td><strong>Inlet pressure (barA)</strong></td>
<td>19.0</td>
<td>7.1</td>
<td>18.5</td>
<td>19.0</td>
<td>10.0</td>
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<tr>
<td><strong>Outlet pressure (barA)</strong></td>
<td>7.5</td>
<td>1.25</td>
<td>4.5</td>
<td>10.0</td>
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<tr>
<td><strong>Inlet temperature (K)</strong></td>
<td>43.5</td>
<td>18.9</td>
<td>7.6</td>
<td>80</td>
<td>66.1</td>
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<tr>
<td><strong>Helium mass flow (g/s)</strong></td>
<td>98</td>
<td>98</td>
<td>147</td>
<td>110</td>
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<tr>
<td><strong>Isothermal efficiency (%)</strong></td>
<td>&gt;= 75.5</td>
<td>&gt;= 77.0</td>
<td>&gt; 70.0</td>
<td>&gt;= 79.6</td>
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<tr>
<td><strong>Cooling power (W)</strong></td>
<td>5333</td>
<td>3577</td>
<td>1100</td>
<td>8193+9057</td>
<td></td>
</tr>
<tr>
<td><strong>Nominal Speed (rpm)</strong></td>
<td>187000</td>
<td>107500</td>
<td>120000</td>
<td>181000</td>
<td>161000</td>
</tr>
</tbody>
</table>
**Upgraded DeltaV DCS: centralized supervisory, distributed control**

- Three-layer redundant control network and expands function through OPC protocol
- New compressors and turbines PLC communicate with DCS through MODBUS/PROFIBUS DP protocol
## Latest I/O List of ECS

<table>
<thead>
<tr>
<th>I/O</th>
<th>MYCOM Compressors</th>
<th>Compressor Station</th>
<th>Helium Refrigerator</th>
<th>New Turbine</th>
<th>Distribution Subsystem</th>
<th>Magnets THS, HTS CL</th>
<th>Total</th>
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<tbody>
<tr>
<td>AI</td>
<td>66</td>
<td>89</td>
<td>122</td>
<td>60</td>
<td>108</td>
<td>341</td>
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<td>AO</td>
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<td>48</td>
<td>20</td>
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<td>DI</td>
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<td>17</td>
<td>52</td>
<td>24</td>
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<td>218</td>
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<tr>
<td>DO</td>
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<td>69</td>
<td>22</td>
<td>18</td>
<td>68</td>
<td>/</td>
<td>185</td>
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<tr>
<td>Total</td>
<td>92</td>
<td>277</td>
<td>209</td>
<td>150</td>
<td>246</td>
<td>371</td>
<td>1345</td>
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</tbody>
</table>

### Various process parameter types
- Temperature, Pressure, Pressure difference, Mass flow rate, Liquid level, Rotation speed, Gas purity, Vacuum degree, Power, Displacement…

### Various controlled parameters
- 17 pressure, 20 temperature, 6 liquid level, 19 flow rate, 8 rotation speed, 4 purity

### ~160 PID control loops for cryogenic process control
### Operation Timetable of ECS

#### 1. Start Cooling Date

<table>
<thead>
<tr>
<th></th>
<th>1st</th>
<th>2nd</th>
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<td>26th</td>
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<td>DEC,</td>
<td>JUN,</td>
<td>FEB,</td>
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<td>AUG,</td>
<td>JAN,</td>
<td>MAY,</td>
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<td>AUG,</td>
<td>MAY,</td>
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#### 2. 300~80K Pre-cooling Time

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<th>3rd</th>
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<td>Days</td>
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<td>11</td>
<td>13</td>
<td>15</td>
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<td>12</td>
<td>14</td>
<td>14</td>
<td>18</td>
<td>16</td>
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#### 3. 80~4.5K Cool-down Time

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<th>4th</th>
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<tr>
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<td>5</td>
<td>6</td>
<td>6</td>
<td>6</td>
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#### 4. 4.5K State Time

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<tbody>
<tr>
<td>Days</td>
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<td>28</td>
<td>57</td>
<td>50</td>
<td>79</td>
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<td>148</td>
<td>138</td>
<td>73</td>
<td>131</td>
<td>140</td>
<td>38...</td>
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#### 5. Warm-up Time

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<td>7</td>
<td>7</td>
<td>12</td>
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#### 6. Operation Time

<table>
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<tr>
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<th>10th</th>
<th>11th</th>
<th>12th</th>
<th>13th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>45</td>
<td>87</td>
<td>52</td>
<td>84</td>
<td>77</td>
<td>107</td>
<td>139</td>
<td>173</td>
<td>163</td>
<td>100</td>
<td>163</td>
<td>173</td>
<td>60...</td>
</tr>
</tbody>
</table>

#### Total Operation Time

1423 days till the end of June, 2017
EAST Cool-down after Upgrade

妮 *300~80 K Pre-cooling*
  - PF, TF, cases and THS cool-down simultaneously and automatically to maintain temperature gradients within 50K to avoid the destruction by heat stress

妮 *80~4.5 K cool-down*
  - New turbines operate automatically after upgrade; the whole refrigerator will operate in auto mode in near future

妮 *4.5 K steady state operation*

### 12th Cool-down
**2016.8.10-2016.9.2**

### 13th Cool-down
**2017.5.2-2017.5.23**

300 K-80 K
~18 days

80 K-4.5 K
~5 days

300 K-80 K
~16 days

80 K-4.5 K
~6 days
**New compressors**

- Complete the start process to reach nominal mass flow within half an hour
- Pressures controlled stable
- operated continuously over 2 months in automatic mode without any problem

HP = 20 ± 0.03 bar

LP = 1.04 ± 0.01 bar
New Turbines TB&TC Operation

🌟 Big break power gas bearing helium turbine with eddy current brake

- Operated with Rotor Cooling Circuit (RCC)
- Total braking capacity can reach 10 kW
- Fully dynamic radial gas bearings
- Lower thrust gas bearing is static to increase thrust carrying capacity
- Easy operation, fast and stable startup: 4 min
- PLC control system control turbines’ automatic start/stop and protection

🌟 Long term stable mechanical and control performance
**New Turbine TD Operation**

- **Full dynamic gas bearing turbine with eddy current brake**
  - Fast brake response
  - Easy operation, fast and stable startup: only 2 min
  - High automation degree
  - Long period stable operation for 5 cool-down experiments

Inlet and outlet pressure fluctuate during Charging period
Reliability Analysis

Abnormal events and faults (2006~2017)

Fault Proportion Chart

- Turbines
- Compressors
- Power Supply Failure
- Pipeline Leak
- Instrumentation
- Valve Leak or Failure
- Exchanger Blocked
- Helium Circulators
- DCS(Controller)
- Gas Supply Failure
- Oil Ring Pump
- Others

Turbines & Compressors fault stop
- happened before upgrade
- caused by mechanical failure; cannot be restarted in short time again
- never happened again after upgrade (2015-)

Turbines protection stop
- happened several times after upgrade
- caused by other failures only consumed several hours to recover to normal

<table>
<thead>
<tr>
<th>Fault Type</th>
<th>Fault proportion</th>
<th>Effects in EAST cryogenic system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbines fault stop</td>
<td>52%</td>
<td>Cool-down can’t continue; can’t maintain the cooling, the magnets required discharge in 4.5 K steady state</td>
</tr>
<tr>
<td>Compressors fault stop</td>
<td>25%</td>
<td>The cryogenic system cannot maintain operating in any operational mode</td>
</tr>
<tr>
<td>Leak (gas/oil)</td>
<td>4%</td>
<td>Bring economic losses; oil leak may contaminate to the system which could cause other failures</td>
</tr>
<tr>
<td>Power supply failure</td>
<td>4%</td>
<td>May cause compressors/turbines stop or damage to them or helium gas losses</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>3%</td>
<td>Influence process monitoring or automatic control</td>
</tr>
<tr>
<td>Valve (blocked/leak)</td>
<td>3%</td>
<td>Blocked valve may cause the system stop; bring economic losses</td>
</tr>
<tr>
<td>Heat exchangers blocked</td>
<td>3%</td>
<td>Decrease the efficiency or may cause the system stop</td>
</tr>
<tr>
<td>Helium circulators</td>
<td>2%</td>
<td>Can’t maintain the forced-flow cooling, the magnets required discharge in 4.5 K steady state</td>
</tr>
<tr>
<td>DCS failure(controller)</td>
<td>1%</td>
<td>The cryogenic system cannot be operated or controlled</td>
</tr>
<tr>
<td>Gas supply failure</td>
<td>1%</td>
<td>Control valve came into Fail state, could cause turbines protection stop or influence normal operation</td>
</tr>
<tr>
<td>Oil ring pump</td>
<td>1%</td>
<td>Can’t maintain 3.8 K cooling, back to 4.5 K operation</td>
</tr>
<tr>
<td>Others</td>
<td>1%</td>
<td>Can be restored in time, didn’t have too much effect in normal operation</td>
</tr>
</tbody>
</table>
Conclusion and Perspective

Compressor system, turbine system and cryogenic control system have been upgraded and operated for latest three cool-down experiments since 2015, and been verified the long term stability and reliability.

Lower fault rate and helium gas leakage, lower power supply consumption and higher automation degree and refrigeration power.

Proposal for higher reliability will be considered:
- The spare turbines on standby within cold box should be considered to allow resuming plasma operation in less than one day.
- The reparation spare for critical components as well as each type of instrumentation must be available on site.
- The vibration of new compressors should be monitored and analyzed for preventive maintenance.
- Spare recovery compressor should be arranged in parallel on standby in case of gas losses in emergency.

Fully automatic control for the whole refrigerator in the experiment in future, especially automatic control in case of emergent fault.
Acknowledgements

 Emblematic Engineering Division for their expertise of the EAST cryogenic system.

 Financial support by the National Natural Science Foundation of China (Grant No. 11505237) and the Science Foundation (DSJJ16GC02) within the Institute of Plasma Physics, Chinese Academy of Sciences.

Thanks for your attention!